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S. Schwartz
R. T. Jennings
J. F. Kimmons
R. P. Mouser,
C. L. Weinzapfel
M. R. Kozlowski
C. J. Stolz
J. H. Campbell

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Lawrence Livermore National Laboratory
P.O. Box 808, L-496
Livermore, CA 94551-0808

ABSTRACT

A sizable laser damage metrology effort is required as part of optics production and installation for the 192 beam National Ignition Facility (NIF) laser. The large quantities, high damage thresholds, and large apertures of polished and coated optics necessitates vendor-based metrology equipment to assure component quality during production. This equipment must be optimized to provide the required information as rapidly as possible with limited operator experience. The damage metrology tools include: 1) platinum inclusion damage test systems for laser amplifier slabs, 2) laser conditioning stations for mirrors and polarizers, and 3) mapping and damage testing stations for UV transmissive optics. Each system includes a commercial Nd:YAG laser, a translation stage for the optics, and diagnostics to evaluate damage. The scanning parameters, optical layout, and diagnostics vary with the test fluences required and the damage morphologies expected. This paper describes the technical objectives and milestones involved in fulfilling these metrology requirements at multiple vendors.

KEYWORD LIST

Laser damage, laser damage metrology, NIF metrology, National Ignition Facility, large area conditioning, laser glass damage tester, 3ω damage testing.

1. INTRODUCTION

Excluding spares, 3072 laser glass slabs, 1220 high damage threshold e-beam deposited mirrors and polarizers, and 768 transmissive UV (3ω) optical elements are required to construct NIF. Laser metrology instruments are required for the production of each of these meter-class components. The laser damage systems provide a different manufacturing QA function for each optic type. Laser slab production requires the use of 1.064 μm laser energy for the detection of bulk platinum inclusions. High damage threshold e-beam deposited coatings require 1.064 μm laser conditioning to increase the functional damage threshold of the coating, as well as provide data during irradiation which is valuable in monitoring the deposition process. Damage testing at 355 nm is the base-line technique for the QA of 3ω SiO_2 optical elements. In this case damage probability curves are generated and compared to the specification as pass/fail criteria.

The damage QA facilities vary primarily in the laser wavelength and the diagnostic packages used to monitor the sample under test. Figure 1 shows a typical large aperture damage test system layout, neglecting the sample plane diagnostics. The laser source is a commercially available Spectra Physics Nd:YAG operating at 10 or 30 Hz depending on the system. The energy is focused to a far-field, diffraction limited focus in the sample plane. The sample plane spatial beam profile is shown in Figure 2. The sample is translated through the beam to irradiate the entire surface area by raster scanning. A bare SiO_2 wedge is used to redirect a calibrated sampling of the beam to an energy meter and the CCD camera of a commercial beam profiling system. The control computer monitors these diagnostics, acting on any fluctuations. Figure 3 shows a typical damage metrology laboratory.

2. LASER GLASS DAMAGE TEST SYSTEMS

Platinum inclusions near or below the visual detection limit (1-50 μm diameter) are present in most Nd:glass material. To aid in the detection of these inclusions at the material vendor site, a laser glass damage test (LGDT) system irradiates the laser slab with 1.064 μm 10 ns laser pulses with fluences of 6 – 14 J/cm^2 (see Figure 4). Since the Pt is highly absorbing at 1ω, illumination results in the fracture of the glass surrounding the inclusion. The fractured material (with diameters on the order of 100s of μm) is easily detected by post irradiation visual inspection.

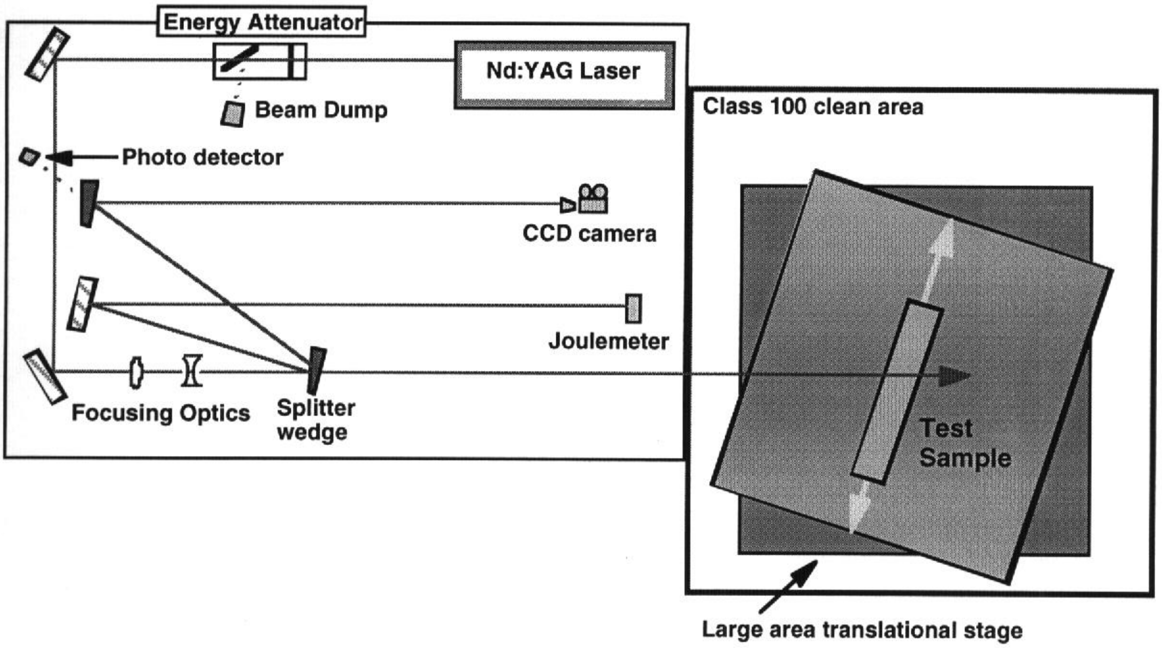

Figure 1. Typical large-aperture laser damage metrology system layout.

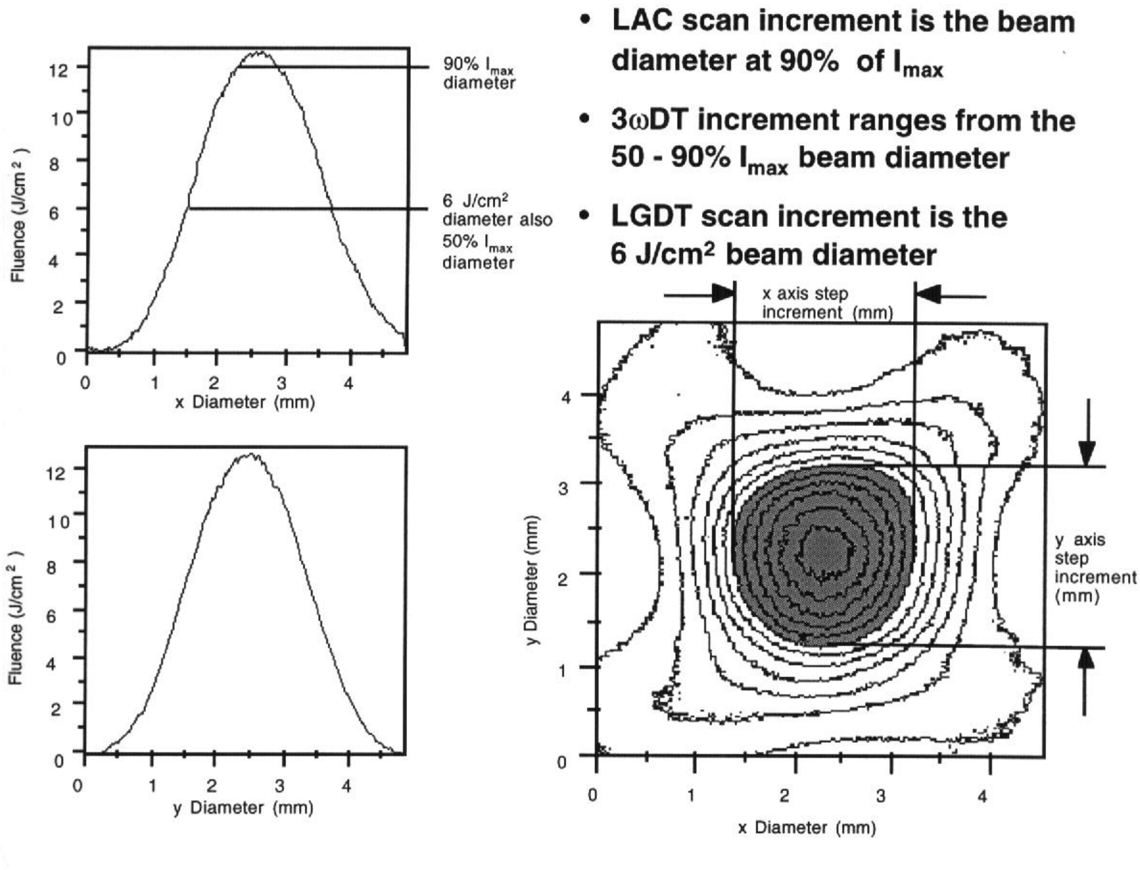

Figure 2. Far-field diffraction limited spatial beam profile in the sample plane. Step sizes during scanning are chosen to assure illumination of all points at a minimum fluence specific to the test.

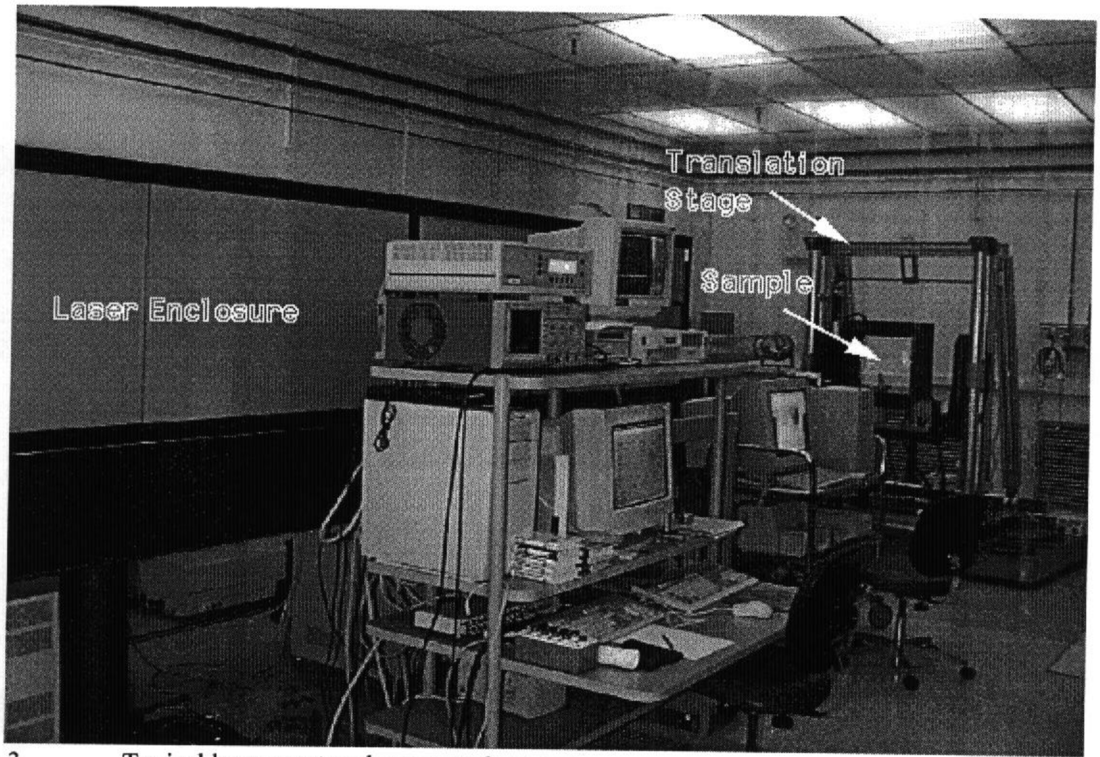

Figure 3. Typical large aperture laser metrology system.

The raster scan translation increment between laser pulses at 30 Hz is determined by the control computer using the measured Gaussian width at the 6 J/cm^2 level (see Figure 2). This scan increment is on the order of 2 mm. A 50 x 80 cm laser slab can be scanned in less than six hours.

During the scanning, the beam profile in the sample plane is continuously monitored by the control computer. If the peak energy should reach 16 J/cm^2 (near the intrinsic damage threshold of the laser glass) an error routine is entered which prompts the operator to identify the cause of the fluctuation. If the 6 J/cm^2 beam diameter should increase or decrease, the scanning increment is adjusted dynamically. Any deviation from a nominal beam parameter is recorded on the hard disk of the control computer. Additional features performed by the Lab View driven control computer are automated system warm-up and shut-down routines, on screen operation and troubleshooting guides, and simplified test execution through an intuitive, step-by-step user interface.

After the full aperture of an optic is scanned, the material is visually inspected for Pt-related damage and evaluated relative to the manufacturing specifications.

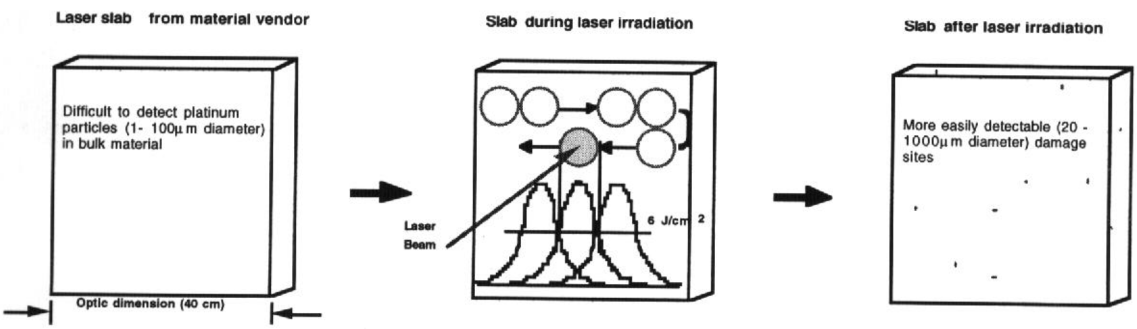

Figure 4. Graphical representation of the use of the LGDT system to enable the visual detection of Pt inclusions.

3. LASER CONDITIONING SYSTEMS FOR E-BEAM COATINGS

Polarizers and high reflectors manufactured by multilayer e-beam deposition have demonstrated a 2x improvement in functional damage threshold when conditioned by 1.064 μm energy[1]. This increase is required to insure damage threshold performance of NIF polarizers operating at up to 10.5 J/cm^2 and transport mirrors operating at peak energies of 21.9 J/cm^2 at 3 ns. It is for this purpose that large area conditioning (LAC) stations are being implemented at NIF coating vendor sites. In addition to conditioning the coating, QA and process feedback operations generate scatter maps (depicting surface uniformity), optic lifetime predictions, and plasma statistics. The conditioning effect is largely attributed to the gentle removal of coating defects (nodules).[2,3,4] Plasma counting provides feedback as to increases or reductions in the quantity of coating defects. The plasma map provides spatial information as to the location of these occurrences.

Large aperture coatings are conditioned off-line in the same fashion as laser slabs are irradiated: raster scanning a small (1-2 mm diameter) Gaussian beam across the full aperture of the optic. The control computer determines the scan increment by using the measured Gaussian width at 90% of peak intensity value (see Figure 2). Full aperture conditioning of a typical optic requires 24 hours. A single scan can be utilized for conditioning since the leading edge of the Gaussian at adjacent sites is used to pre-irradiate each area prior to the peak fluence, as illustrated in Figure 5. Before each laser pulse (occurring at 30 Hz) the area to be irradiated is imaged onto a detector which measures the light scattered from the surface. Next, the laser pulse irradiates the surface, as another detector reading is made to acquire any plasma signal that may be present. Ten microseconds later, a second scatter measurement is taken which characterizes the area after irradiation. Each 'before', 'after', and plasma measurement is recorded as a function of position in order to generate scatter and plasma maps. By subtracting the scatter map after irradiation from the scatter map prior to irradiation (referredto as Δscatter), the areas of greatest signal change due to damage can be identified. In order to evaluate the risk posed by the conditioning-induced damage, the system automatically identifies five sites of the largest Δscatter magnitude and continues to irradiate them ten additional times while monitoring defect growth with a 100x CCD optical microscope. From this repeated irradiation, the growth rate is determined and a curve is generated which predicts when the largest defect will reach a diameter equal to the largest allowable site specification for the optic under test. The number of additional shots required to exceed this specification is the predicted optic lifetime.

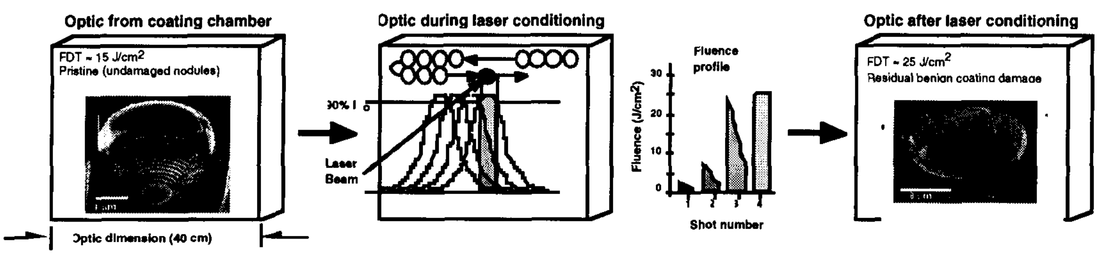

Figure 5. Graphical representation of the raster scanning laser conditioning process.

Since conditioning must occur at a specific peak fluence, the peak energy is held to within ±5% of nominal by computer control of the energy attenuator. The diagnostic alignment is accomplished by focusing an integrated CCD camera on an alignment aperture. The laser beam is also aligned to this aperture. The operator selects the type of optic being tested from a control menu. Given this information, the computer loads the test aperture, conditioning fluence(s), and verifies that the operator has the optic under test installed at its use angle. At this point the optic is scanned unattended. If an error should occur requiring operator input, the system is capable of issuing an alpha numeric radio page alerting the user of the status.

The projected optic lifetime, plasma count, and plasma histogram are made available at the vendor site. The test parameters, growth data, projected lifetime curve, scatter maps, plasma count, plasma map, and plasma histogram are transferred to LLNL.

4. 355 NM DAMAGE TEST SYSTEM FOR FUSED SILICA

A single number generated by repeated irradiation of a few dozen test sites (S/1) is no longer adequate to describe the probabilistic nature of damage at high energies over large apertures. To better describe the performance of these optics, "extreme statistics" are used which make use of a damage probabilities generated during off-line raster scanning. This probability leads to the calculation of a Weibull coefficient[5], allowing a predicted damage density as a function of fluence to be calculated. This predicted damage density is used as a pass/fail criteria by comparison with a damage density curve specified for each optic type. Some of the NIF elements will be irradiated by as much as 15 J/cm^2 of 351 nm laser energy over 3 ns. In addition to providing damage probability predictions, the damage data can be monitored for indications of changing finishing processes parameters such as contamination of the slurry.

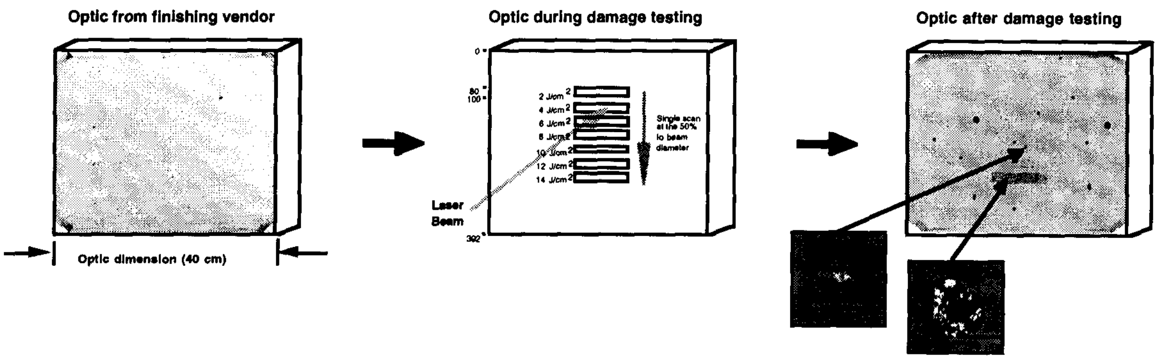

Figure 6. Graphical representation of QA verification of large aperture 355 nm damage performance.

Current planning indicates that the 3ω damage test system will be operated at the Lawrence Livermore National Laboratory (LLNL) due to the cost of vendor site installation and the complexity of system operation and maintenance.

Fused silica optics are damage tested off-line in much the same way as the previously described laser metrology equipment. The major differencesare that the 1/e^2 beam diameter is typically 1.5 mm, the laser wavelength is 355 nm, and the entire clear aperture is not irradiated. The control computer determines the scan increment by using the measured Gaussian width at 50% of the peak intensity value (see Figure 2). Prior to testing, the optic is mounted in a fixture which floods the bulk material with white light. A mega-pixel image of the entire optic is acquired which highlights defects within the bulk and on the surface[6]. This is followed by the 3ω irradiation of seven 20 cm^2 areas. Each area is scanned at a differentfluence. After irradiation, a second mega-pixel image is acquired. The image prior to testing is subtracted from the final image and the number of new sites within each test area are counted. In this way a damage probability can be calculated for each test fluence (see Figure 6). Testing a typical optic in this fashion requires 10 days. Through reduction of the test areas and automation of the procedure, it is expected that system capacity will be eight hours per optic.

5. SUMMARY

LLNL is currently involved in placing three types of laser damage based metrology equipment at component vendor sites. Laser slab production requires an LGDT system at the material vendor site for the detection of bulk platinum inclusions. This equipment can process a 500 x 800 mm slab in less than 6 hours. High damage threshold e-beam deposited coatings require the placement of two LAC systems at each coating vendor site to increase the functional damage threshold of the coating, as well as provide rapid QA data. This equipment is capable of processing an optic every 24 hours; 23 of which are unattended and fully automated. Damage threshold verification of 3ω SiO_2 optical elements will be performed at LLNL. Damage probability curves are generated and compared to the specification as pass/fail criteria. One 3ω system is required based on component production rates and testing schedules, assuming that an optic can be tested in 24 hours. Following a statistics-based optimization of the test procedure and automation of the inspection process, the testing rate is expected to be as low as 8 hours per optic.

6. ACKNOWLEDGMENTS

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